US 20160291663A1

(19) **United States**

(12) **Patent Application Publication**

Sun et al.

(10) **Pub. No.: US 2016/0291663 A1**

(43) **Pub. Date: Oct. 6, 2016**

(54) **USB POWER DELIVERY EXTENSION SYSTEM**

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(21) Appl. No.: **15/050,623**

(22) Filed: **Feb. 23, 2016**

Related U.S. Application Data

(60) Provisional application No. 62/119,449, filed on Feb. 23, 2015, provisional application No. 62/201,382, filed on Aug. 5, 2015.

Publication Classification

(51) **Int. Cl.**

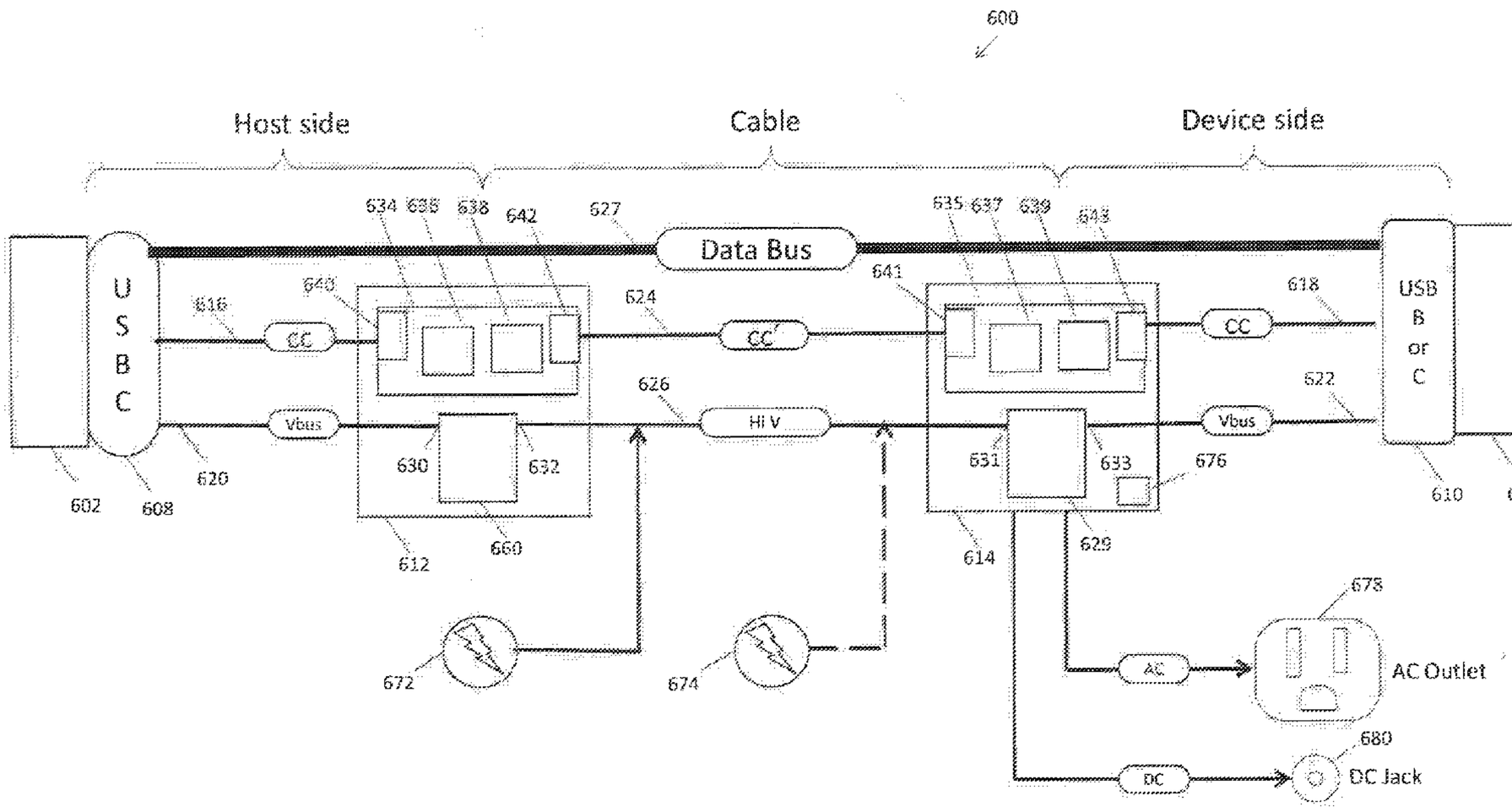
G06F 1/26	(2006.01)
G06F 13/42	(2006.01)
G06F 13/10	(2006.01)
G06F 13/40	(2006.01)
H02M 3/00	(2006.01)
H02M 7/42	(2006.01)

(52) **U.S. Cl.**

CPC ***G06F 1/266*** (2013.01); ***H02M 3/00*** (2013.01); ***H02M 7/42*** (2013.01); ***G06F 13/102*** (2013.01); ***G06F 13/4022*** (2013.01); ***G06F 13/4282*** (2013.01); *G06F 2213/0042* (2013.01)

(57) **ABSTRACT**

Embodiments of a USB cable extension system is disclosed for delivering power to a device via a USB connection. The system can include converter circuitries to convert a voltage supplied via a USB connector to a different voltage for transmission over a power transmission wire and to convert a voltage received from a power transmission wire to a different voltage to be supplied to a USB connector connectable to a device to be powered.



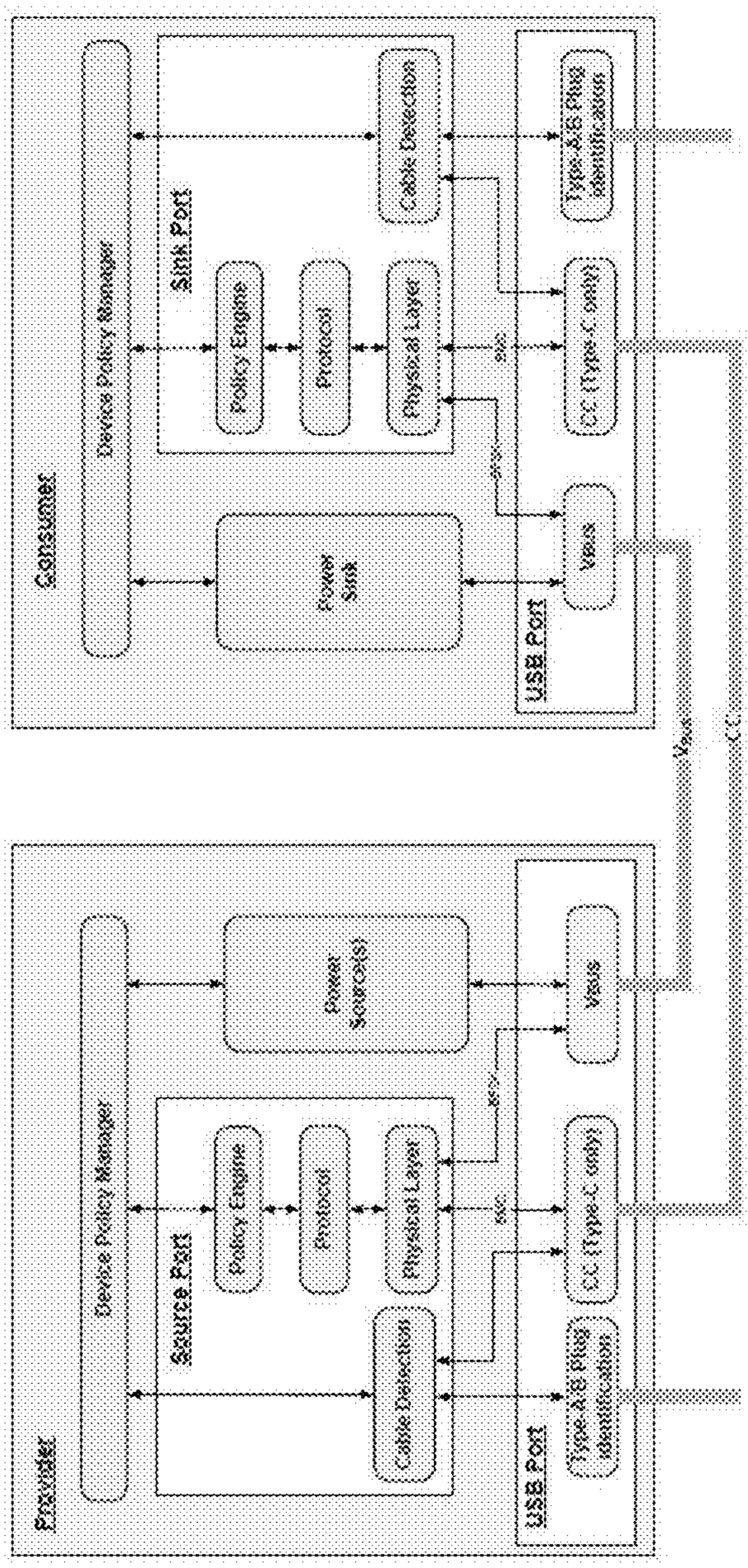

Consumer
Device Policy Manager
Sink Port
Policy Engine
Protocol
Physical Layer
Power Sink
Cable Detection
Type-C State Machine
CC (Type-C only)
VBUS
USB Port
VBUS
CC
Provider
Device Policy Manager
Source Port
Policy Engine
Protocol
Physical Layer
Cable Detection
Power Source(s)
Type-C State Machine
CC (Type-C only)
VBUS
USB Port

FIG. 1

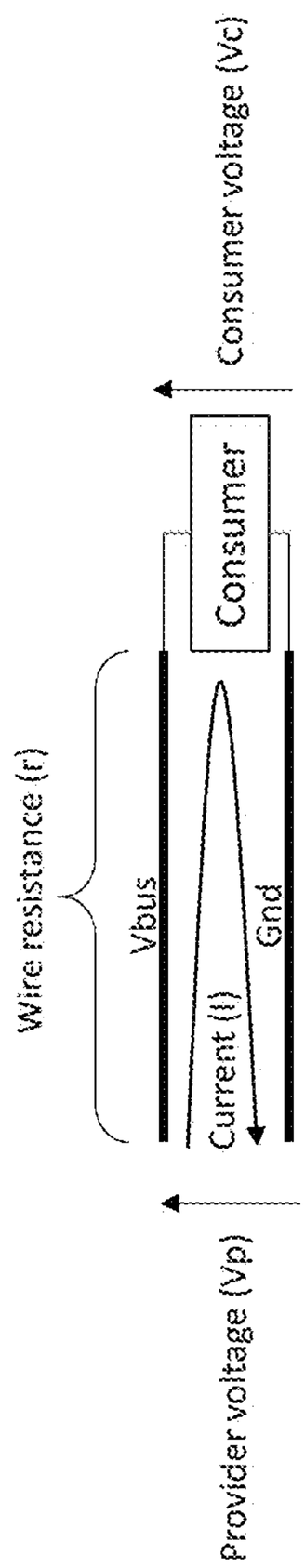

Provider voltage (Vp)
Consumer voltage (Vc)
Consumer
Vbus
Gnd
Current (I)
Wire resistance (r)

FIG. 2

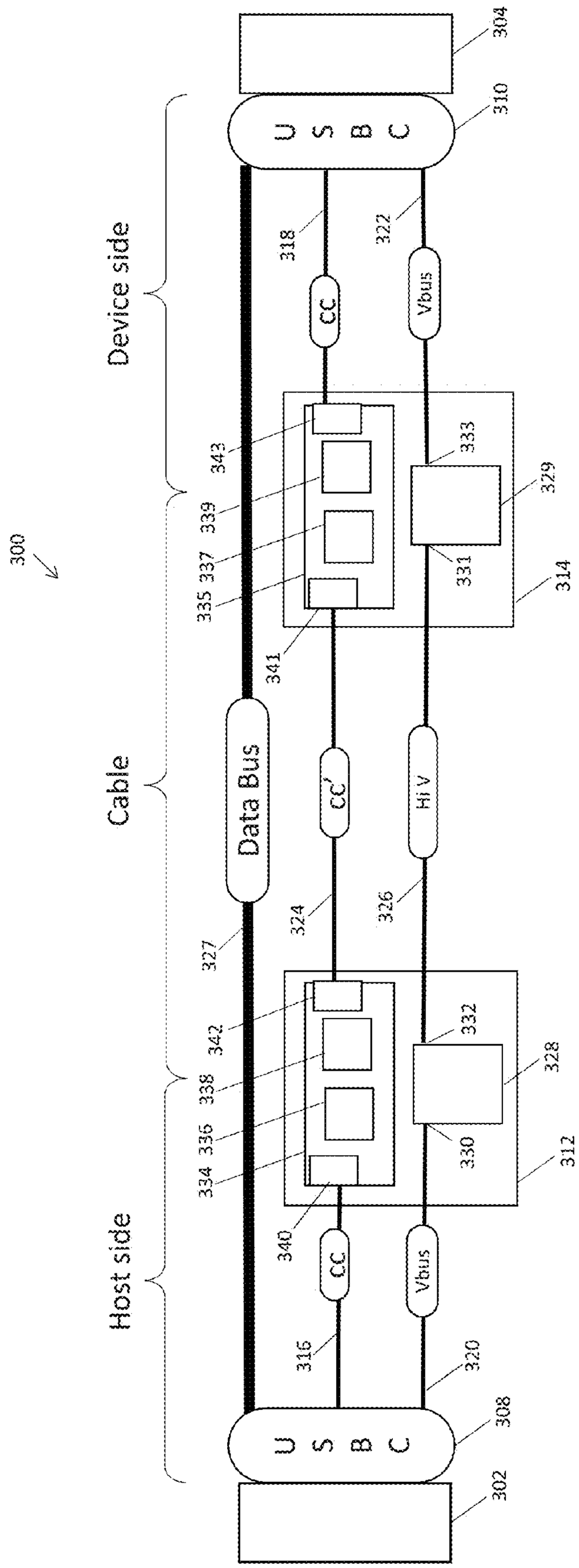

300
Device side
Cable
Host side
304
310
U S B C
318
322
CC
Vbus
342
339
337
335
333
329
331
314
341
Data Bus
CC'
Hi V
327
324
326
342
338
336
334
332
328
330
312
340
316
320
308
302

FIG. 3

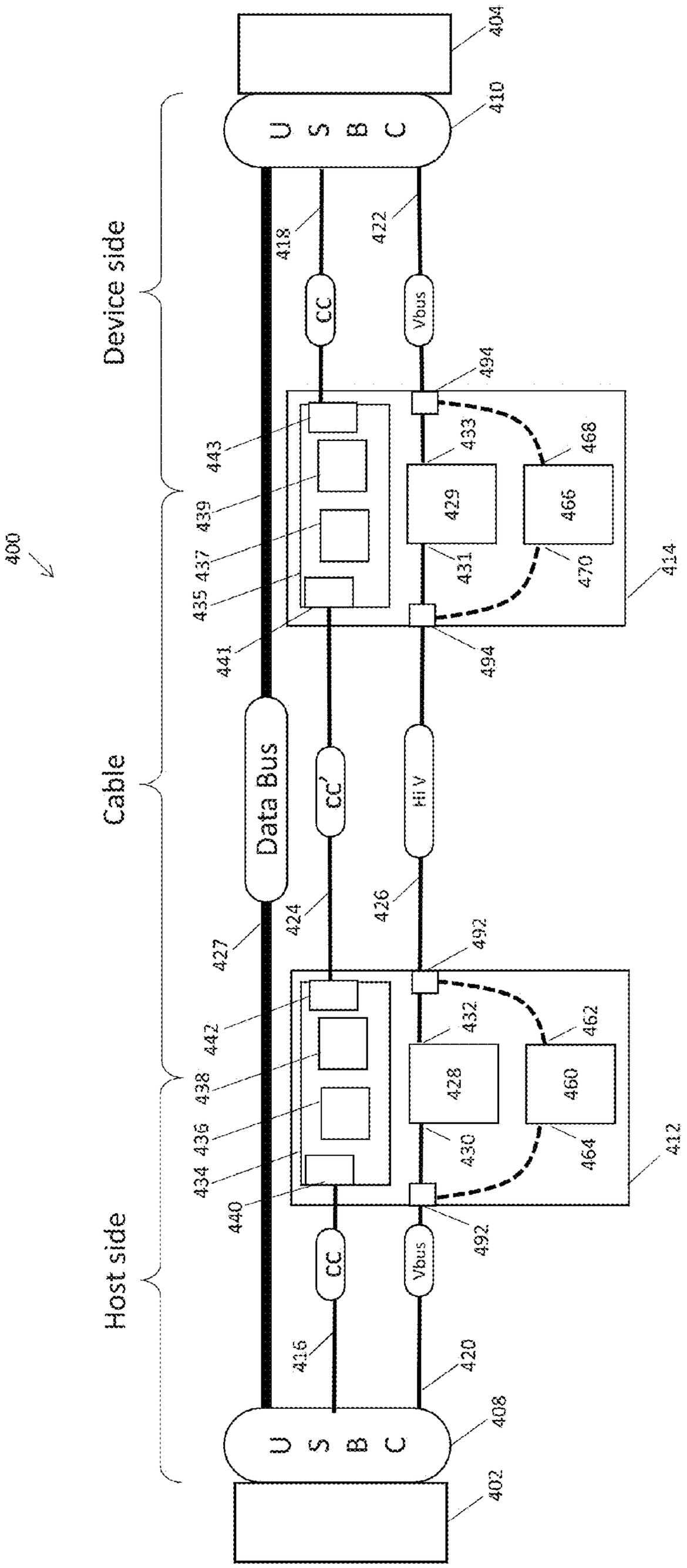

400
Device side
Cable
Host side
USBC
404
410
418
422
CC
Vbus
494
443
439
437
435
441
433
468
429
465
431
470
414
Data Bus
CC'
Hi V
424
426
427
492
442
438
436
434
440
432
462
428
460
430
464
412
416
420
408
402

FIG. 4

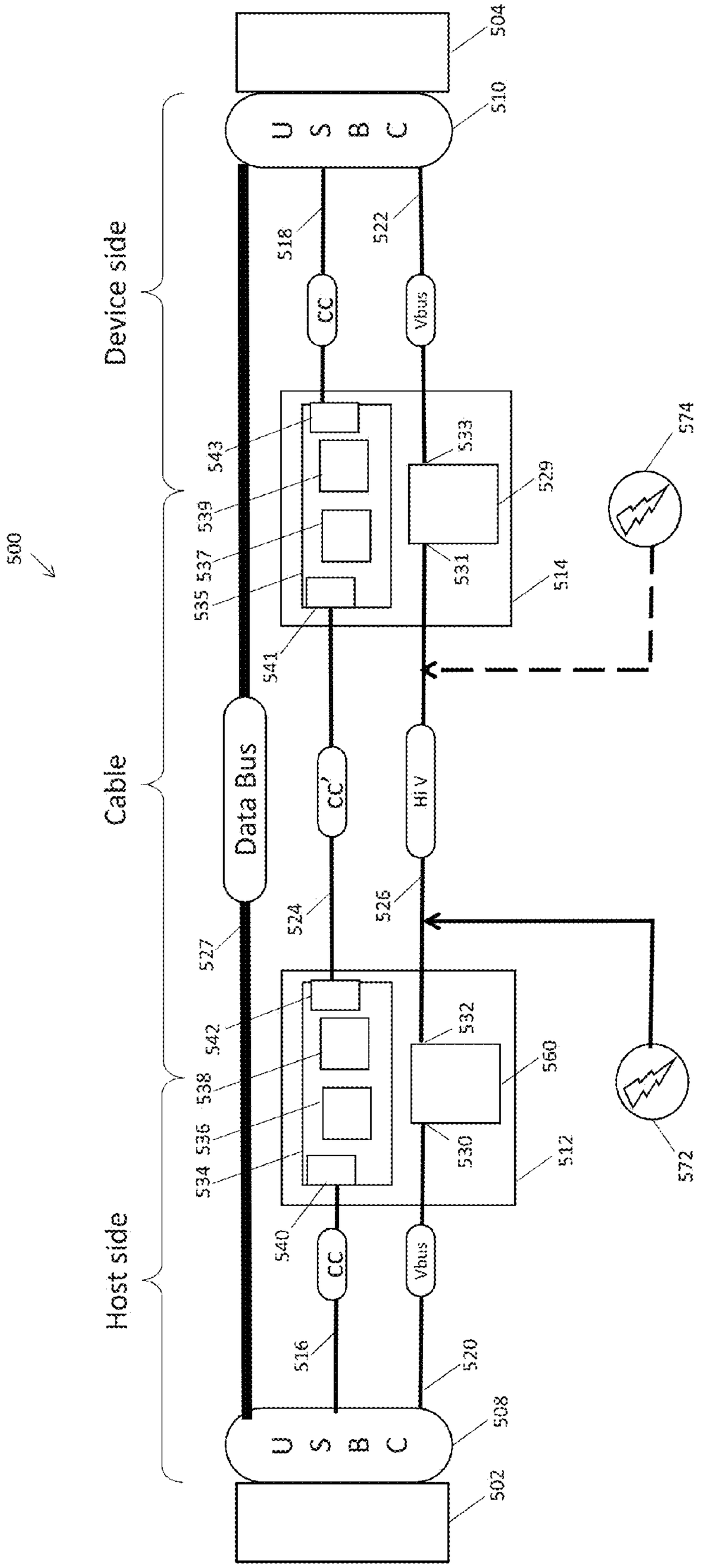

500
Device side
Cable
Host side
USBC
504
510
518
522
CC
Vbus
543
539
535
537
533
529
531
514
541
574
572
Data Bus
CC'
Hi V
524
526
527
542
538
536
534
532
560
530
512
540
516
520
508
502

FIG. 5

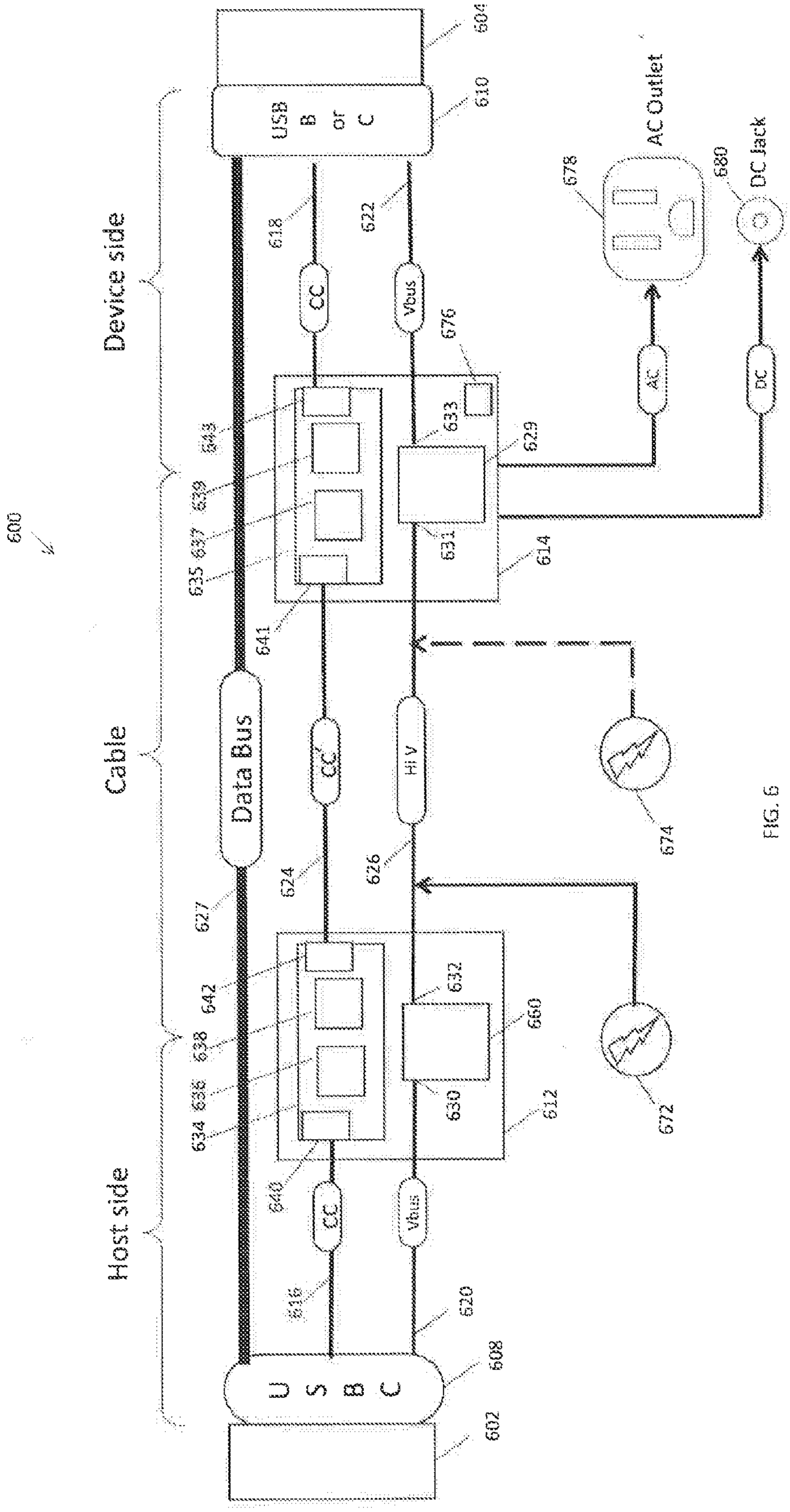

600
Device side
Cable
Host side
USB B or C
604
610
618
622
CC
Vbus
676
643
639
637
635
633
629
631
614
641
AC Outlet
678
680
DC Jack
AC
DC
Data Bus
CC'
Hi V
624
626
627
674
642
638
636
634
632
660
630
612
672
640
616
620
608
602
U S B C

FIG. 6

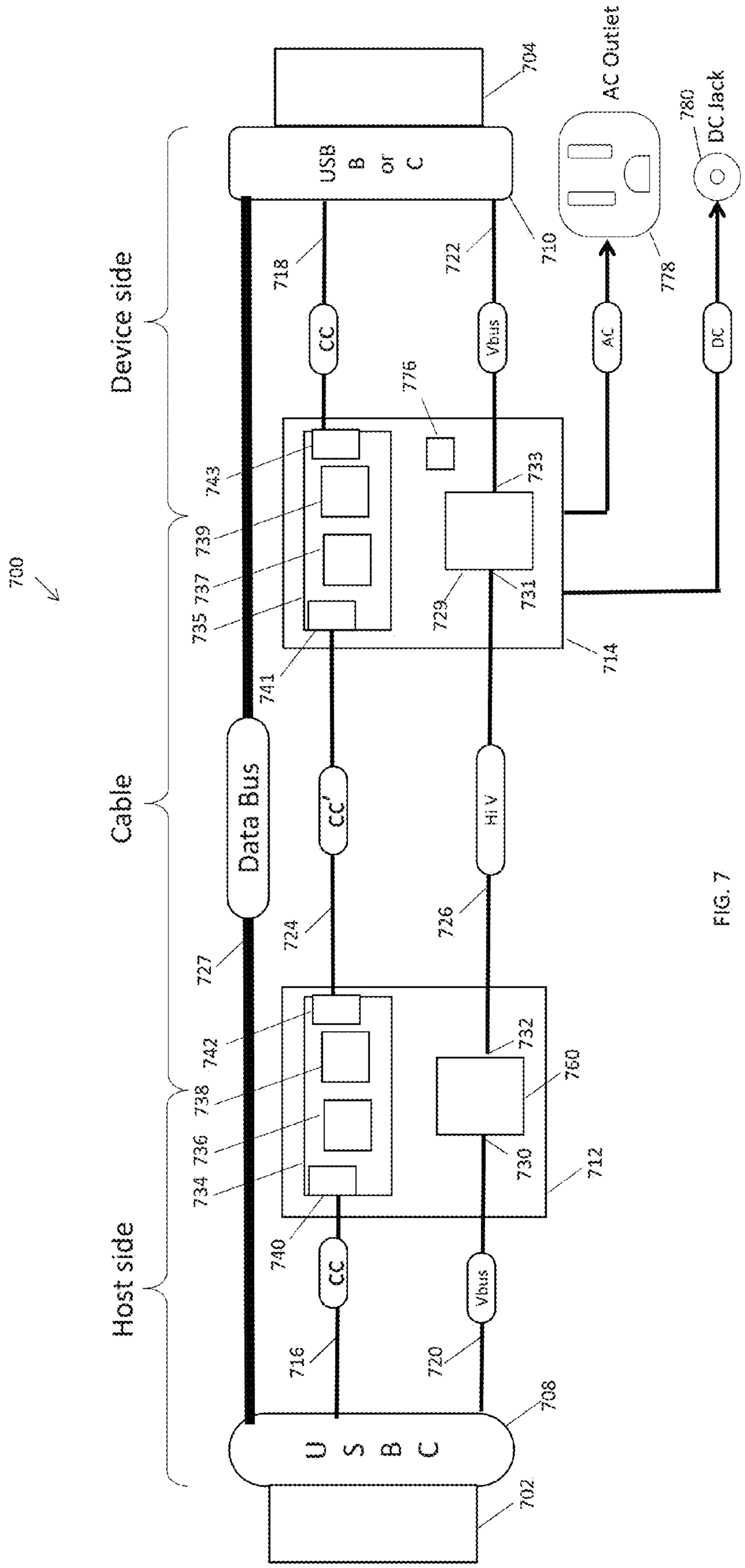

730
Device side
Cable
Host side
USB B or C
704
AC Outlet
780
DC Jack
718
722
710
778
CC
Vbus
AC
DC
776
743
739
735 737
733
729
731
714
741
Data Bus
CC'
Hi V
724
726
727
742
738
736
734
732
760
730
712
740
716
720
708
USBC
702

FIG. 7

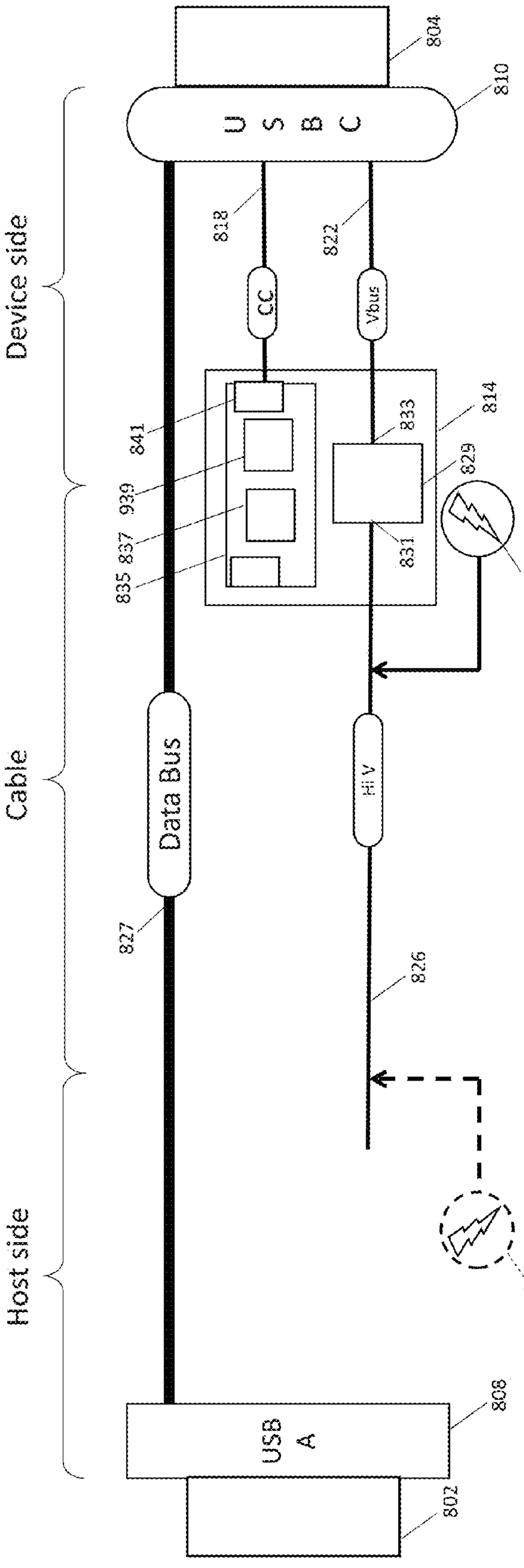

800
Device side
Cable
Host side
804
810
USBC
818
822
CC
Vbus
841
939
837
835
833
814
829
831
874
827
Data Bus
Hi V
826
872
808
USB A
802

FIG. 8

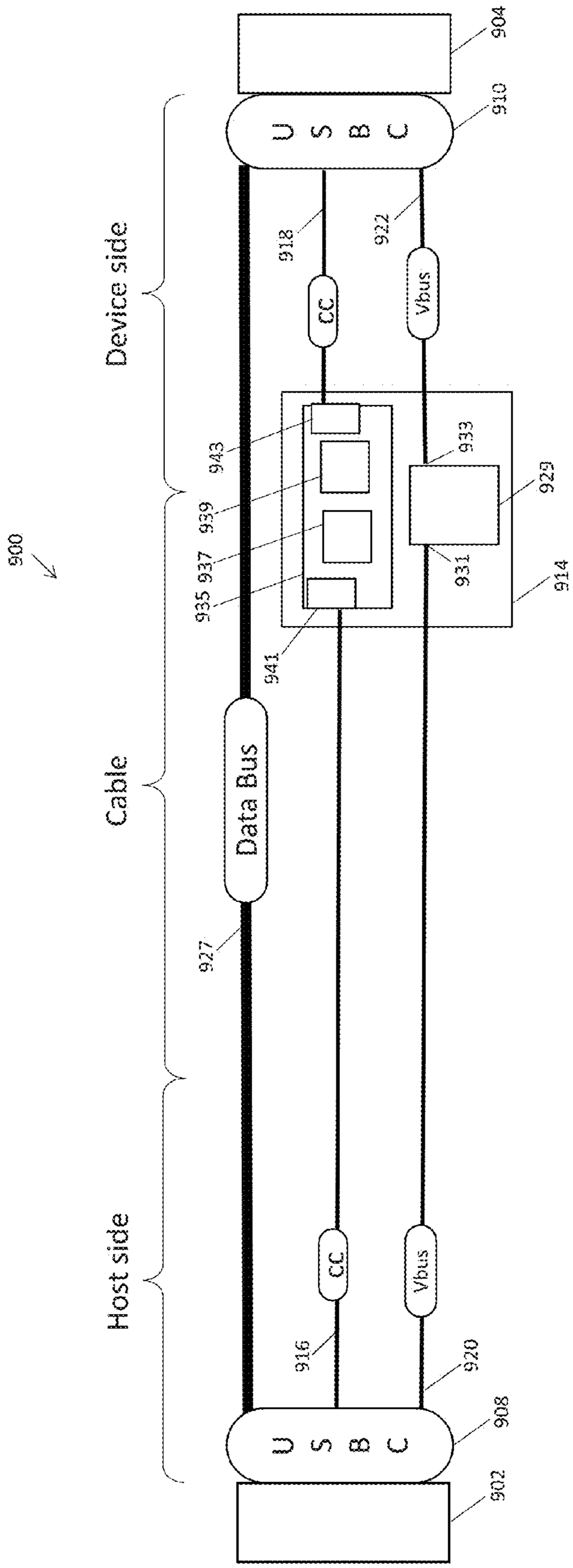

900
Device side
Cable
Host side
904
910
USBC
918
922
CC
Vbus
943
939
935
937
933
929
931
914
941
927
Data Bus
916
920
908
902

FIG. 9

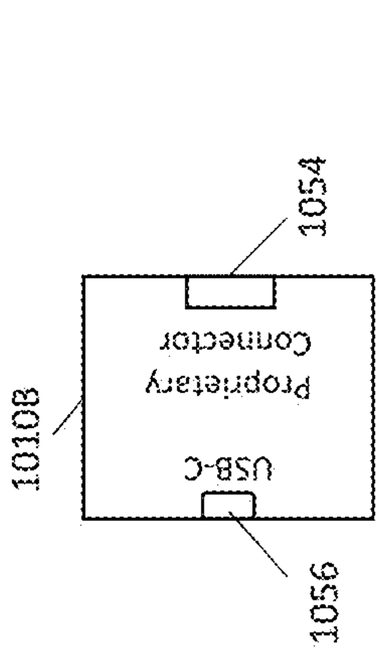


FIG. 10B

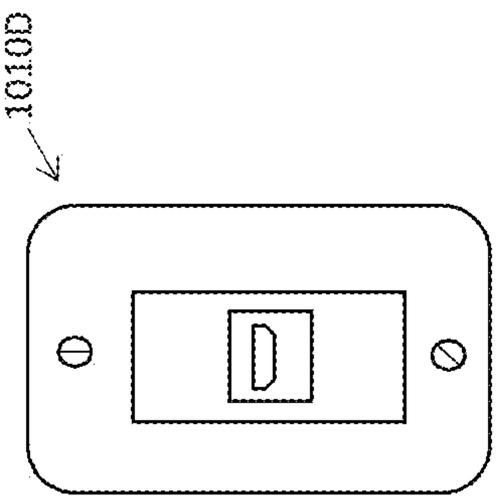


FIG. 10D

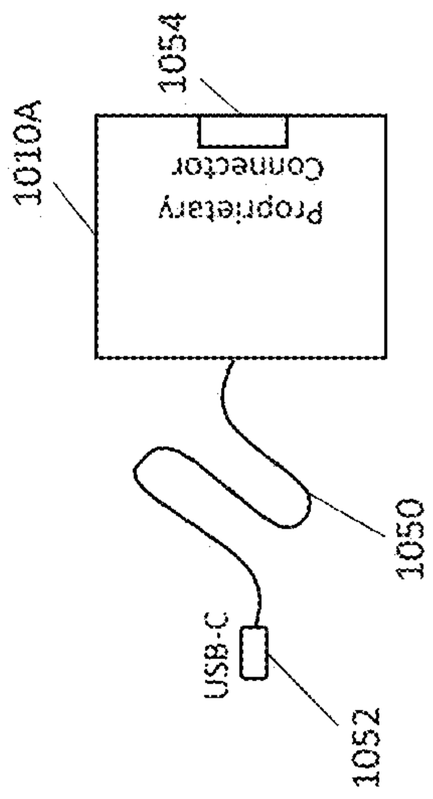


FIG. 10A

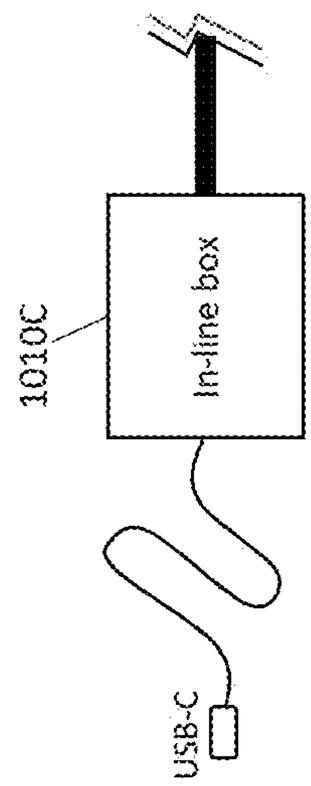


FIG. 10C

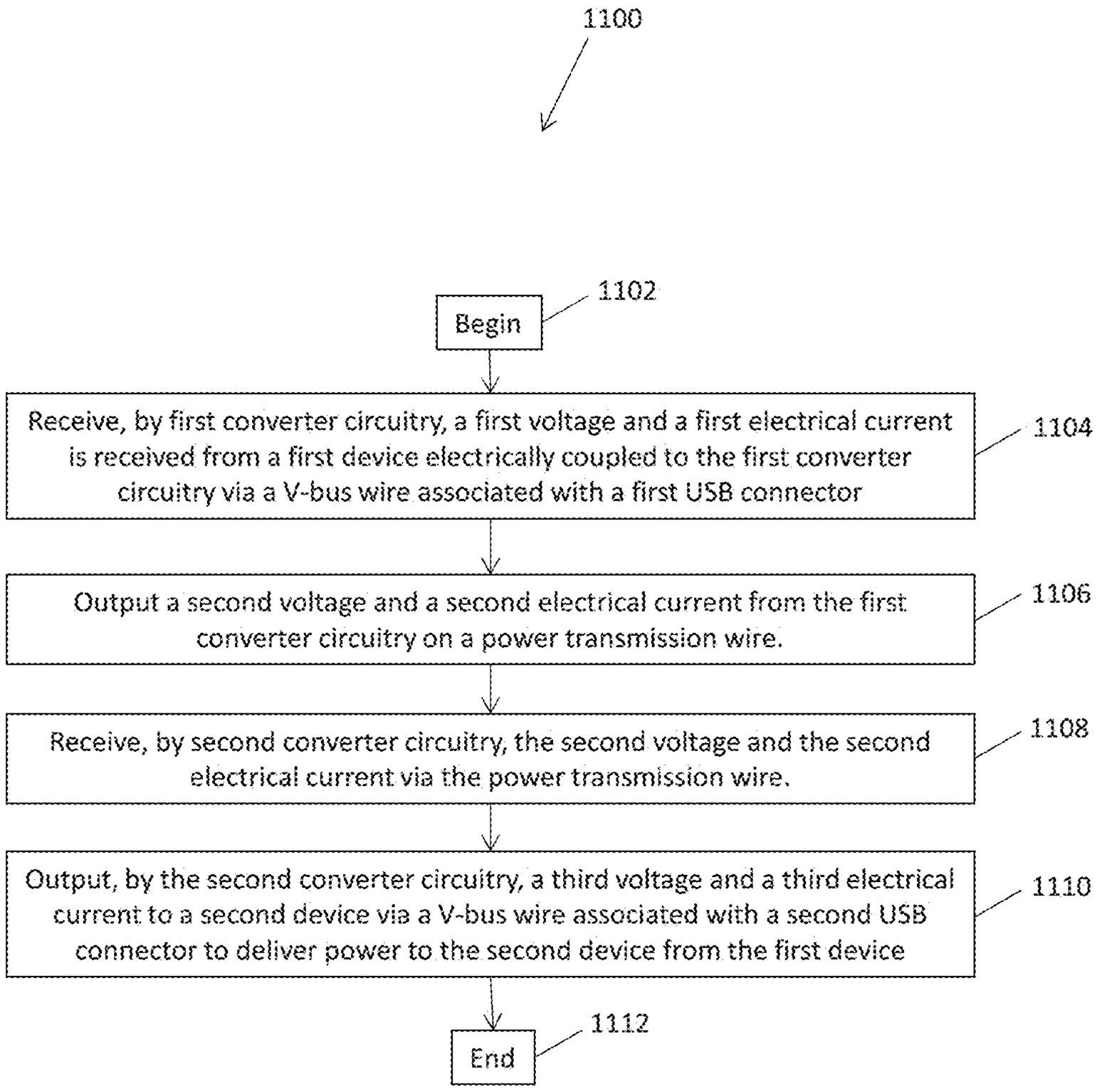

1100
Begin
1102
Receive, by first converter circuitry, a first voltage and a first electrical current is received from a first device electrically coupled to the first converter circuitry via a V-bus wire associated with a first USB connector
1104
Output a second voltage and a second electrical current from the first converter circuitry on a power transmission wire.
1106
Receive, by second converter circuitry, the second voltage and the second electrical current via the power transmission wire.
1108
Output, by the second converter circuitry, a third voltage and a third electrical current to a second device via a V-bus wire associated with a second USB connector to deliver power to the second device from the first device
1110
End
1112

FIG. 11

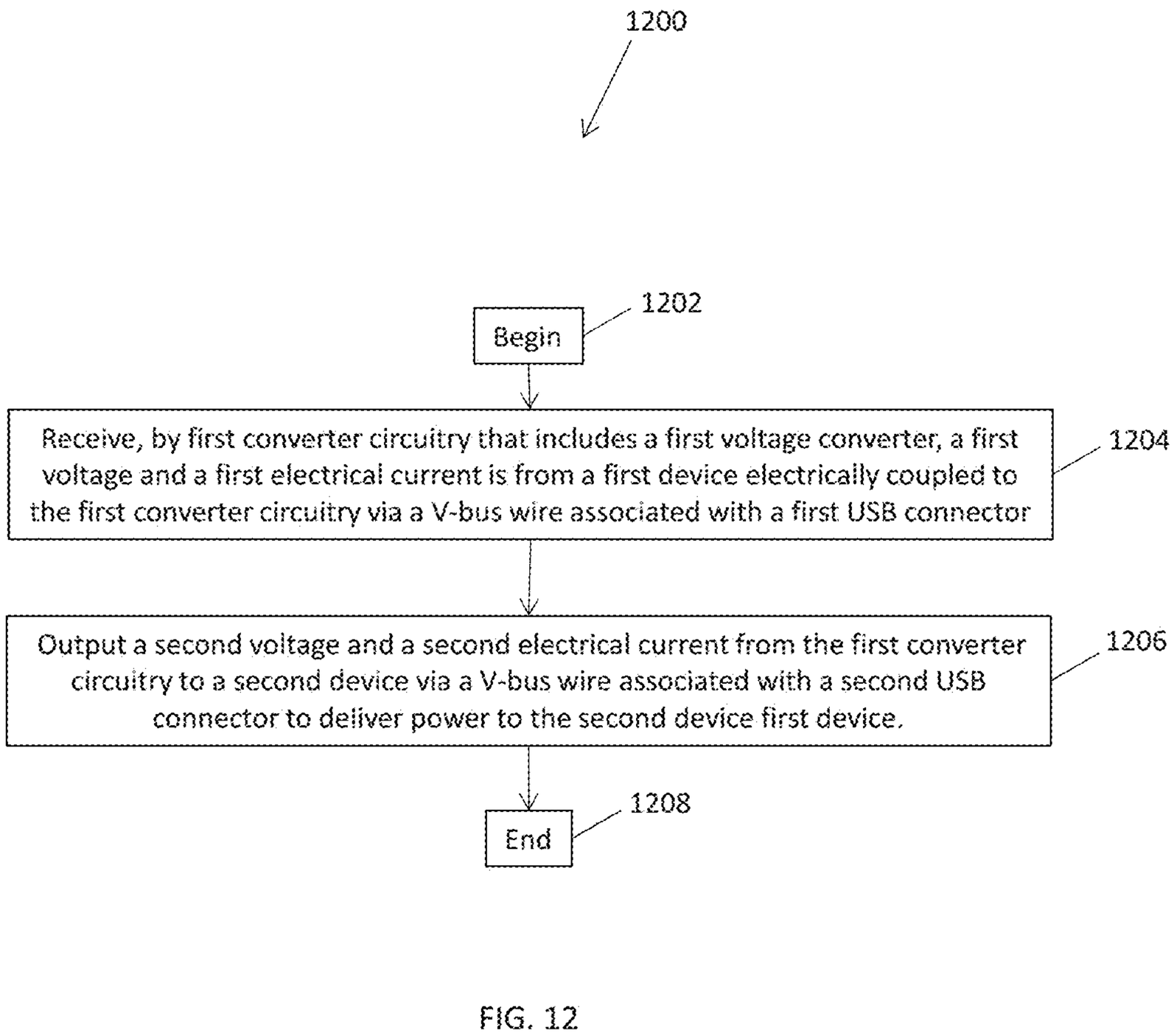

1200
Begin
1202
Receive, by first converter circuitry that includes a first voltage converter, a first voltage and a first electrical current is from a first device electrically coupled to the first converter circuitry via a V-bus wire associated with a first USB connector
1204
Output a second voltage and a second electrical current from the first converter circuitry to a second device via a V-bus wire associated with a second USB connector to deliver power to the second device first device.
1206
End
1208

FIG. 12

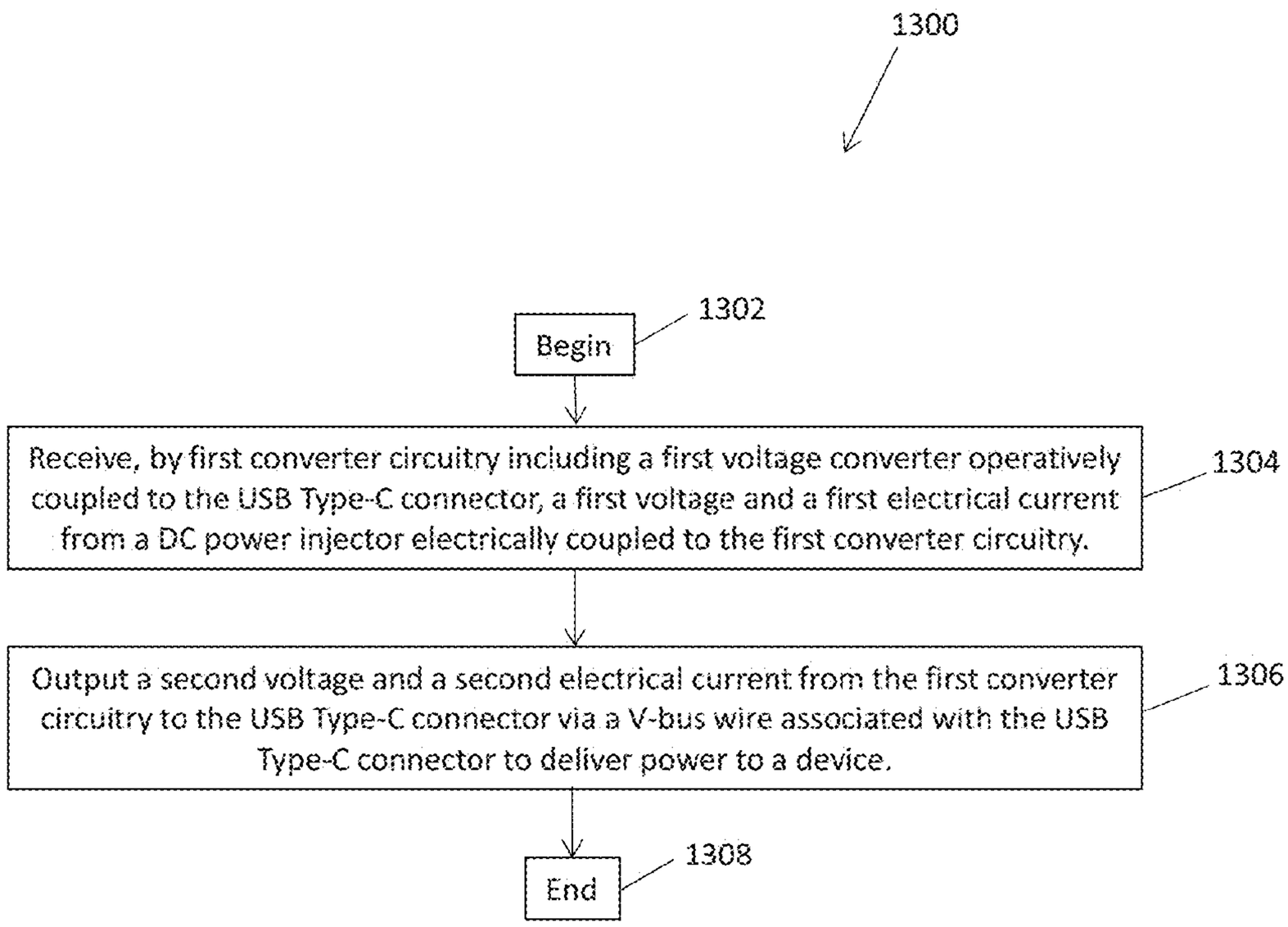

1300
Begin
1302
Receive, by first converter circuitry including a first voltage converter operatively coupled to the USB Type-C connector, a first voltage and a first electrical current from a DC power injector electrically coupled to the first converter circuitry.
1304
Output a second voltage and a second electrical current from the first converter circuitry to the USB Type-C connector via a V-bus wire associated with the USB Type-C connector to deliver power to a device.
1306
End
1308

FIG. 13

USB POWER DELIVERY EXTENSION SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claim priority to U.S. Provisional Application No. 62/119,449, filed on Feb. 23, 2015, and U.S. Provisional Application No. 62/201,382 filed on Aug. 5, 2015, the disclosures of which are incorporated by reference herein in their entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to Universal Serial Bus ("USB") cables.

BACKGROUND

[0003] In general, the use of USB cables to provide data connections between electronic devices has increased in popularity over the last decade. Today, USB cables are commonly used to connect devices, including smart phones, cameras, keyboards, mice, etc., to, for example, a desktop or laptop personal computer. In addition to data transmission, older versions of the USB specification provided for low-level power delivery that was only sufficient for charging small electronic devices. For example, the USB 2.0 specification provided for delivery of two and a half watts (2.5W) of power, enough to charge a portable music player. The USB 3.0 specification provided for delivery of four and a half watts (4.5W) of power, enough to charge a cell phone. The USB Battery Charging 1.2 specification provided for delivery of seven and a half watts (7.5W) of power, enough power to charge a digital camera, but prohibited data transmission when delivering power at that level.

[0004] A USB Power Delivery specification was first released in 2012, and version 2.0 (V2.0) of the USB Power Deliver specification was released in 2014. FIG. **1** schematically depicts the architecture of a USB power delivery (PD) connection. The Power Delivery specification provides for delivery of up to one hundred watts (100W) of power via USB cables while simultaneously transmitting data. In particular, the Power Delivery specification includes a profile—one of multiple profiles—for supply of twenty volts (20V) of voltage and five amperes (5A) of current via a USB cable. This profile makes it possible to power laptop computers and disk drives using a USB cable. Additionally, simplified connections between devices are possible. For example, a laptop computer that was previously connected to a display device such as a flat-panel TV, e.g., by an HDMI cable, can now also be charged by the TV—which is itself powered through an AC wall outlet—without increasing the number of cables (e.g., by replacing the HDMI cable with a USB PD connection). A single USB cable can provide the necessary power and data connection between the TV and the laptop.

[0005] One advantage of the USB Power Delivery specification is that it permits power flow in both directions. As such, a connected device can act as a power source to the device at the other end of the cable and/or can act as a power sink for the other device. The two devices are able to negotiate their sink/source roles as well as the voltage and current requirements over the USB cable. In a USB cable with Type-A or Type-B connector, this negotiation is done over the same wire that delivers the power—the VBUS wire—using frequency shift key (FSK) modulation.

[0006] The recent USB 3.1 specification defines a new Type-C connector. Unlike the Type-A and Type-B plugs, the Type-C plug does not have to be oriented in particular top-bottom configuration to mate with the socket. USB cables that have Type-C connectors have a separate wire known as the configuration channel (CC) that is used—instead of VBUS—for the negotiation of power-requirements between connected devices.

[0007] The availability of true power delivery over USB cables makes longer runs of cable more desirable. Currently, a typical USB cable is three to ten feet in length. However, with the USB PD specification, it may now be desirable to connect a display such as a flat-panel TV to a laptop computer that is operated by a user sitting on a couch at the opposite end of the room from a display. Similarly, the display may be connected to a disk drive that is located in a discrete location in another part of the room. As such, longer cable lengths for USB cables become more desirable. For example, for a particular application a 100-foot cable may be desirable.

[0008] With longer cable runs, the voltage drop over the distance of the cable presents a problem, especially at higher currents. FIG. **2** schematically shows a USB cable connected to a power consuming device. The cable contains two power wires—VBUS and Gnd—connected to both the power supply and the consumer device to create a circuit loop. If the gauge of the wires are AWG#22 wires (dia. 0.644 mm) and each wire is one hundred feet long (100 ft.), then each wire will have a resistance of approximately one and six tenths ohms (1.6Ω). If the power supply is twenty volts (20V) and the current draw of the system at twenty volts (20V) is five amperes (5A), then the voltage drop across each wire is eight volts (8V) according to Ohm's law (5A*1.6Ω=8V). The combined voltage drop across the cable is sixteen volts (16V) (e.g., 2*8V=16V). This only allows for a four volt (4V) voltage drop across the device, which is below the voltage rating for most electronic devices. If the gauge of the wires are AWG#18 wires (dia. 1.024 mm), then each one hundred foot (100 ft.) wire will have a resistance of approximately six tenths ohms (0.60Ω). In that case, for a twenty volt (20V) power supply and five amperes (5A) of current, the combined voltage drop across both wires in the cable would be approximately six volts (6V). This allows for a fourteen volt (14V) voltage drop across the consumer device, which is enough for some but not all consumer applications. For example, more than fourteen volts (14V) is generally required to charge a laptop battery.

[0009] Another power delivery profile supported by the USB Power Delivery specification is ten watts (10W) of power at five volts (5V) and two amperes (2A). For this profile, a one hundred foot (100 ft.) USB cable using two AWG#22 gauge power wires requires approximately a six and four tenths volt (6.4V) voltage drop across its length (2*2A*1.6Ω=6.4V), which means it cannot work with a five volt (5V) power source. A one hundred foot (100 ft.) USB cable using two AWG#18 gauge power wires would require approximately a two and four tenths volt (2.4V) voltage drop across its length, meaning that only two and six tenths volts (2.6V) is available at the consumer device. This amount of voltage is insufficient for most consumer electrical devices.

SUMMARY

[0010] Exemplary embodiments of the present disclosure advantageously provide for a USB cable extension system

that facilitates power delivery using USB connectors and cables by compensating for cable impedances within the USB cable to ensure that a sufficient voltage and/or electrical current is provided to a device electrically coupled to a power receiving end of the USB cable. Exemplary embodiments can use one or more voltage converters to convert the voltage received from a device or other source to a different voltage that may be suitable for transmission of relatively long cables while reducing the effect of the impedance of the cables.

[0011] In accordance with embodiments of the present disclosure, a Universal Serial Bus power delivery system is disclosed. The system includes first converter circuitry. The first converter circuitry includes a first controller and a first voltage converter. The first controller has a first electrical interface configured to electrically couple to a CC wire of a first USB Type-C connector. The controller is configured to send and receive data via the first electrical interface. The first voltage converter has an input and an output. The first voltage converter is configured to receive a first voltage at the input and to output a second voltage at the output. The first voltage converter is configured so that (i) the input of the voltage converter is configured to be electrically coupled to a V-bus wire of the USB Type-C connector and the output of the first voltage converter is configured to be electrically coupled to a power transmission wire or (ii) the input of the first voltage converter is configured to be electrically coupled to the power transmission wire and the output of the first voltage converter is configured to be electrically coupled to the V-bus wire of the USB Type-C connector.

[0012] In accordance with embodiments of the present disclosure, a method of delivering power via a Universal Serial Bus cable is disclosed. The method includes receiving, by first converter circuitry, a first voltage and a first electrical current from a first device electrically coupled to the first converter circuitry via a V-bus wire associated with a first USB connector; and outputting, from the first converter circuitry, a second voltage and a second electrical current on a power transmission wire. The second voltage is greater than the first voltage and the second electrical current is less than the first electrical current. The method also includes receiving, by second converter circuitry, the second voltage and the second electrical current via the power transmission wire; and outputting, from the second converter circuitry, a third voltage and a third electrical current to a second device via a V-bus wire associated with a second USB connector.

[0013] In accordance with embodiments of the present disclosure, a method of delivering power via a Universal Serial Bus cable is disclosed that includes receiving, by first converter circuitry including a first voltage converter, a first voltage and a first electrical current from a first device electrically coupled to the first converter circuitry via a V-bus wire associated with a first USB connector; and outputting, from the first converter circuitry, a second voltage and a second electrical current to a second device via a V-bus wire associated with a second USB connector.

[0014] In accordance with embodiments of the present disclosure, a method of delivering power via a Universal Serial Bus cable having a USB Type-C connector at a first terminal end of the Universal Serial Bus cable and an USB Type-A connector at a second end of the Universal Serial Bus cable, is disclosed. The method includes receiving, by first converter circuitry including a first voltage converter operatively coupled to the USB Type-C connector, a first voltage and a first electrical current from a DC power injector electrically coupled to the first converter circuitry. The method also includes outputting, from the first converter circuitry to the USB Type-C connector, a second voltage and a second electrical current via a V-bus wire associated with the USB Type-C connector.

[0015] Any combination and permutation of embodiments is envisioned. Other embodiments, objects, and features will become apparent from the following detailed description considered in conjunction with the accompanying drawings. It is to be understood, however, that the drawings are designed as an illustration only and not as a definition of the limits of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Exemplary embodiments of the present disclosure will be understood from the following detailed description when read with the accompanying Figures. In the drawings, like reference numerals refer to like parts throughout the various views of the non-limiting and non-exhaustive embodiments.

[0017] FIG. **1** (Prior Art) is a schematic depiction of the architecture of the USB Power Delivery specification;

[0018] FIG. **2** (Prior Art) is a schematic depiction of the power wires inside of a USB cable;

[0019] FIG. **3** is a schematic depiction of a USB connection with a power-delivery extender according to an embodiment of the present disclosure;

[0020] FIG. **4** is a schematic depiction of a bidirectional USB connection with a power-delivery extender according to an embodiment of the present disclosure;

[0021] FIG. **5** is a schematic depiction of a USB connection with a power-delivery extender including DC power injectors according to an embodiment of the present disclosure;

[0022] FIG. **6** is a schematic depiction of a USB connection with a power-delivery extender including DC power injectors, voltage outlets and jacks according to an embodiment of the present disclosure;

[0023] FIG. **7** is a schematic depiction of a USB connection with a power-delivery extender including voltage outlets and jacks according to an embodiment of the present disclosure;

[0024] FIG. **8** is a schematic depiction of a USB connection with a power-delivery extender including DC power injectors to provide power according to an embodiment of the present disclosure;

[0025] FIG. **9** is a schematic depiction of a USB connection with a power-delivery extender including a single instance of converter circuitry according to an embodiment of the present disclosure; and

[0026] FIGS. **10**A-D show exemplary form factors for housing embodiments of converter circuitry in accordance with exemplary embodiments of the present disclosure.

[0027] FIG. **11** is a flowchart of a non-limiting example power delivery process **1100** in accordance embodiments of the present disclosure.

[0028] FIG. **12** is a flowchart of a non-limiting example power delivery process **1200** in accordance with embodiments of the present disclosure.

[0029] FIG. **13** is a flowchart of a non-limiting example power delivery process **1300** in accordance with embodiments of the present disclosure.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0030] Exemplary embodiments of the present disclosure relate to devices, systems, methods, and computer-readable media related to power delivery using universal serial bus (USB) connectors and cables. Exemplary embodiments of the present disclosure compensate for cable impedances within USB cables to ensure that a sufficient voltage and/or electrical current is provided to device(s) electrically coupled to a power receiving end of the USB cable.

[0031] Exemplary embodiments can include one or more converter circuits that are configured to adjust the voltages and currents being transmitted over a USB cable and/or being transmitted to and/or from electronic devices operatively coupled to the USB cable. The converter circuits can be dynamically configurable to accommodate different voltage, current, and/or power ratings associated with devices to that can be operatively coupled to converter circuits and/or to accommodate USB Power Deliver standards. In exemplary embodiments, the one or more converter circuits can be integrally formed with a USB cable such that a unitary cable is provided that can be connected between device and/or can be formed as separate stand-alone devices having a housing with one or more ports for receiving connectors of one or more cables.

[0032] FIG. **3** shows a schematic representation of a USB cable extension system **300** making a USB connection between a first device **302** having a first USB port **308** and a second device **304** having a second USB port **310**. USB ports **308** and **310** are Type-C ports that each have two configuration channel (CC) pins and four VBUS pins. The cable extension system **300** includes first converter circuitry **312** and second converter circuitry **314**. In exemplary embodiments, the first converter circuitry **312** and second converter circuitry **314** can each be disposed within a respective housing or other suitable structure (e.g., having connectors and/or ports to facilitate electrically coupling the converter circuitry **312**, **314** to other connectors, ports and/or devices). The devices **302**, **304**, the ports **308**, **310** and the converter circuitry **312**, **314** are all partially or fully compliant with the USB Power Delivery specification. The converter circuitry **312**, **314** can be connected to each other and to ports **308**, **310** in different ways, as described below.

[0033] The connections between ports **308**, **310** and their respective converter circuitry **312**, **314** each contain a CC wire **316**, **318** that is connected to a CC pin on their respective port for data communication between the port and the converter circuitry and a VBUS wire **320**, **322** that is connected to a VBUS pin on their respective port for power transmission between the port and the connector circuitry. The connection between the converter circuitry **312** and **314** contain a CC communication channel (through the CC' connection **324** whose physical media is not necessarily copper wires) for data transmission between converter circuitry **312** and **314** and a power transmission or high voltage wire **326** for power transmission between the converter circuitry **312** and **314**. It should be understood that VBUS wires **320**, **322** and high voltage wire **326** have associated ground wires (not shown) that make up a return path for the power-delivering current. A data bus **327** runs between ports **308**, **310**. The data bus **327** is shown logically as unbroken, i.e., not passing through the converter **312** and **314**, but it should be understood that physically the bus can be made up of wires in the connection between port **308** and the converter circuitry **312**, the connection between circuitry **312** and **314**, and the connection between converter circuitry **314** and port **310**. The wires making up data bus **327** can be copper wires. Alternatively, the wires making up data bus **327** can be optical fiber.

[0034] Converter circuitry **312** includes a step-up voltage converter **328**. Voltage converter has an input **330** connected to the VBUS wire and an output **332** connected to the high voltage wire **326**. Voltage converter **328** is able to produce at the output a voltage that is greater than the voltage at the input. Converter circuitry **312** also includes a controller **334** that includes a microprocessor **336**, a memory **338**, a CC wire interface **340** and a CC communication channel interface **342**. Controller **334** can send and receive information/data on CC wire **316** and can send and receive information/data on CC communication channel (through the CC' connection **324**). Controller **334** can also control voltage converter **328** to control the amount of voltage step up. Alternatively, voltage converter **328** can provide only a fixed step-up of the voltage without controlled adjustment.

[0035] Converter circuitry **314** includes a step-down voltage converter **329**. Voltage converter **329** has an input **331** connected to the high voltage wire **326** and an output **333** that is connected to VBUS wire **322**. Voltage converter **329** is able to produce a voltage at output **333** that is less than the voltage at the input **331**. Converter circuitry **314** also includes a controller **335** that includes a microprocessor **337**, a memory **339**, a CC wire interface **343**, and a CC communication channel interface **341**. Controller **335** can send and receive information/data on CC wire **318** and can send and receive information/data on the CC communication channel (through the CC' connection **324**). Controller **335** can also control voltage converter **329** to control the amount of voltage step down and/or control maximum current available at the output **333**. Alternatively, voltage converter **329** can provide only a fixed step-down of the voltage without controlled adjustment.

[0036] As a non-limiting example, the voltage converter **328** can be configured to step up an input voltage received by the voltage converter **328** to, for example, sixty volts 60V. If the input power has the power profile twenty volts (20V), five amperes (5A), then the current in the circuit on the output side of the voltage converter **328** will be one and sixty-seven hundredths amperes (1.67A) assuming the voltage converter **328** is one hundred percent (100%) efficient such that the power input to the voltage converter **328** equals the power output of the voltage converter **328**. The power input is the input voltage (e.g., 20V) multiplied by the input current (e.g., 5A), and the power output is the output voltage (e.g., 60V) multiplied by the output current. As such, the output current is approximately equal one and sixty-seven hundredths amperes (e.g., 20V*5A/60V=1.67A).

[0037] In an exemplary embodiment, the high voltage wire **326** and its associated ground wire are constructed using AWG#22 gauge wires (dia. 0.644 mm), which each have a resistance of one and six tenths ohms (1.6Ω) per one hundred feet (100 ft.) of length. Continuing the above non-limiting example for AWG#22 gauge wires, at one and sixty-seven hundredths amperes (1.67A) of current, the combined voltage drop across both lengths of wire is approximately five and four tenths volts (5.4V) (e.g., 2*1.67A*1.6Ω=5.4V). Thus, there is approximately fifty-five and six tenths volts (55.6V) available to power the output device and voltage converter **329** can be used to step down

that voltage to the voltage specification for the device being powered, which could be more on the order of, for example, twenty volts (20V).

[0038] In another exemplary embodiment, the high voltage wire **326** and its associated ground wire can be constructed using AWG#18 gauge wires (dia. 0.644 mm), which has a resistance of approximately six tenths ohms (0.60Ω) per one hundred feet (100 ft.) of length. Continuing the above non-limiting example for AWG#18 gauge wires, at one and sixty-seven hundredths amperes (1.67A) of current, the combined voltage drop across both lengths of wire is approximately 2 volts (e.g., 2*1.67A*0.6Ω=2.0V). Thus, there is fifty-eight volts (58V) available to power the output device and voltage converter **329** can be used to step down that voltage to the voltage specification for the device being powered, which could be more on the order of, for example twenty volts (20V).

[0039] Another power delivery profile supported by the USB Power Delivery specification is ten watts (10W) of power at five volts (5V) and two amperes (2A). For this profile, a step up to sixty volts (60V) by voltage converter **328** results in a current of one-hundred sixty-seven milliamperes (167 mA) in the high voltage wire **326** and its associated ground wire running the one hundred foot (100 ft.) length of the USB cable. In the embodiment in which the gauge of those two wires are AWG#22, the combined voltage drop across both lengths of wire is approximately five tenths volts (0.5V) (e.g., 2*0.167A*1.6Ω=0.5V). Thus, there is approximately fifty-nine and five tenths volts (59.5V) available to power the output device and the voltage converter **329** can be used to step down that voltage to the voltage specification for the device being powered, which could be more on the order of, for example, approximately five volts (5V). In the embodiment in which the high voltage wire **326** and its associated ground wire are AWG#**18** gauge wires (dia. 0.644 mm), the combined voltage drop across both lengths of wire is approximately two tenths volts (0.2V) (e.g., 2*0.167A*0.6Ω=0.2V). Thus, there is approximately fifty-nine and eight tenths volts (59.8V) available to power the output device and the voltage converter **329** can be used to step down that voltage to the voltage specification for the device being powered, which could be more on the order of, for example, approximately five volts (5V).

[0040] The device described in the present disclosure has multiple advantages. Power cannot be adequately delivered along a long USB cable length, such as one hundred feet (100 ft.), at the voltages provided for in the USB Power Delivery specification. The system described in the present disclosure steps up the voltage provided by the power supply so that the power can be delivered a longer distance and then steps down the voltage as required at the other end. The step up in the voltage results in a reduction in the current in most of the length of the cable. Because less current is passing the through the wires in the cable along most of its length, an additional advantage is that thinner gauge wires can be used.

[0041] FIG. **4** shows another exemplary cable extension system **400** making a USB connection between a first device **402** having a first USB port **408** and a second device **404** having a second USB port **410**. USB ports **408** and **410** are Type-C ports that each have two configuration channel (CC) pins and four VBUS pins. The cable extension system **400** includes first converter circuitry **412** and second converter circuitry **414**. In exemplary embodiments, the first converter circuitry **412** and second converter circuitry **414** can each be disposed within a respective housing or other suitable structure (e.g., having connectors and/or ports to facilitate electrically coupling the converter circuitry **412**, **414** to other connectors, ports and/or devices). The devices **402**, **404**, the ports **408**, **410** and the converter circuitry **412**, **414** are all partially or fully compliant with the USB Power Delivery specification. The converter circuitry **412**, **414** can be connected to each other and to ports **408**, **410** in different ways, as described herein.

[0042] The connections between ports **408**, **410** and their respective converter circuitry **412**, **414** each contain a CC wire **416**, **418** that is connected to a CC pin on their respective port for data communication between the port and the converter circuitry and a VBUS wire **420**, **422** that is connected to a VBUS pin on their respective port for power transmission between the port and the connector circuitry. The connection between the converter circuitry **412** and **414** contain a CC communication channel (through the CC' connection **424** whose physical media is not necessarily copper wires) for data transmission between converter circuitry **412** and **414** and a power transmission or high voltage wire **426** for power transmission between the converter circuitry **412** and **414**. It should be understood that VBUS wires **420**, **422** and high voltage wire **426** have associated ground wires (not shown) that make up a return path for the power-delivering current. A data bus **427** runs between ports **408**, **410**. The data bus **427** is shown logically as unbroken, i.e., not passing through the converter **412** and **414**, but it should be understood that physically the bus can be made up of wires in the connection between port **408** and the converter circuitry **412**, the connection between circuitry **412** and **414**, and the connection between converter circuitry **414** and port **410**. The wires making up data bus **427** can be copper wires. Alternatively, the wires making up data bus **427** can be optical fiber.

[0043] The converter circuitry **412** contains a step-down voltage converter **460** in addition to step-up converter **428**. The voltage converter **428** has an input **430** that can be selectively connected to the VBUS wire **420** and an output **432** that can be selectively connected to the high voltage wire **426**. The voltage converter **428** is able to produce at the output a voltage that is greater than the voltage at the input. The voltage converter **460** has an input **462** that can be selectively connected to the high voltage wire **426** and an output **464** that can be selectively connected to the VBUS wire **420**. The voltage converter **460** is able to produce at the output **464** a voltage that is less than the voltage at the input **462**.

[0044] The converter circuitry **412** also contains switching circuitry including switches **492** for switching between the voltage converters **428** and **460**. For example, one of the switches **492** can be configured to selectively connect the input **430** of the voltage converter **428** or the output **464** of the voltage converter **460** to the VBUS wire **420** and one of the switches **492** can be configured to selectively connect the output **432** of the voltage converter **428** or the input **462** of the voltage converter **460** to the high voltage wire **426**. In some embodiments, the switches **492** can be formed by transistors, relays, and/or any other suitable switching devices. The switches **492** can be controlled by controller **434** to connect, via the switches **492**, the input **430** and output **432** of the voltage converter **428** to the VBUS wire **420** and the high voltage wire **426**, respectively, while the input **462** and the output **464** of the voltage converter **460**

can be electrically isolated from the VBUS wire **420** and the high voltage wire **426** or to connect, via the switches **492**, the input **462** and output **464** of the voltage converter **460** to the high voltage wire **426** and the VBUS wire **420**, respectively, while the input **430** and the output **432** of the voltage converter **428** can be electrically isolated from the VBUS wire **420** and the high voltage wire **426**.

[0045] The controller **434** can include a microprocessor **436**, a memory **438**, a CC wire interface **440** and a CC communication channel interface **442**. The controller **434** can send and receive information/data on the CC wire **416** and can send and receive information/data on the CC communication channel (through the CC' connection **424**). The controller **434** can control an amount of step-up voltage is generated by the voltage converter **428**. The controller can control an amount of step-down voltage is generated by the voltage converter **460** and/or control a maximum current available at the output **464** of the voltage converter **460**. Alternatively, the voltage converter **428** and/or the voltage converter **460** can provide only a fixed step-up voltage and/or step down voltage, respectively, without controlled adjustment.

[0046] The converter circuitry **414** contains a step-up voltage converter **466** in addition to step-down converter **429**. The voltage converter **429** has an input **431** selectively connected to the high voltage wire **426** and an output **433** that is selectively connected to VBUS wire **422**.

[0047] The voltage converter **429** is able to produce a voltage at output **433** that is less than the voltage at the input **431**. The voltage converter **466** has an input **468** selectively connected to VBUS wire **422** and an output **470** that is selectively connected to the high voltage wire **426**. The voltage converter **466** is able to produce a voltage at output **470** that is greater than the voltage at the input **468**.

[0048] The converter circuitry **414** also contains switching circuitry including switches **494** for switching between the voltage converters **429** and **466**. For example, one of the switches **494** can be configured to selectively connect the input **431** of the voltage converter **429** or the output **470** of the voltage converter **466** to the high voltage wire **426** and one of the switches **494** can be configured to selectively connect the output **433** of the voltage converter **429** or the input **468** of the voltage converter **466** to the VBUS wire **422**. In some embodiments, the switches **494** can be formed by transistors, relays, and/or any other suitable switching devices. The switches **494** can be controlled by controller **435** to connect, via the switches **494**, the input **431** and output **433** of the voltage converter **429** to the high voltage wire **426** and the VBUS wire **422**, respectively, while the input **468** and the output **470** of the voltage converter **466** can be electrically isolated from the VBUS wire **422** and the high voltage wire **426** or to connect, via the switches **494**, the input **468** and output **470** of the voltage converter **466** to the VBUS wire **420** and the high voltage wire **426**, respectively, while the input **431** and the output **433** of the voltage converter **429** can be electrically isolated from the VBUS wire **422** and the high voltage wire **426**.

[0049] The controller **435** can include a microprocessor **437**, a memory **439**, a CC wire interface **443**, and a CC communication channel interface **441**. The controller **435** can send and receive information/data on CC wire **418** and can send and receive information/data on the CC communication channel (through the CC' connection **424**). The controller **435** can also control voltage converter **429** to control an amount of step-down voltage generated by the voltage converter **429** and/or control a maximum current available at the output **433** of the voltage converter **429**. The controller **435** can also control the voltage converter **466** to control an amount of step-up voltage generated by the voltage converter **466** Alternatively, the voltage converters **429** and **466** can provide only a fixed step-down and step-up of the voltages, respectively, without controlled adjustment.

[0050] FIG. **5** shows another exemplary cable extension system **500**. In the system **500** shown in FIG. **5**, converter circuitry **512** includes controller **534** and step down converter **560** and converter circuitry **514** includes controller **535** and step-down converter **529**.

[0051] With reference to the converter circuitry **512**, the controller **534** includes microprocessor **536**, a memory **538**, a CC wire interface **540** and a CC communication channel interface **542**. The controller **534** can send and receive information/data on CC wire **516** and can send and receive information/data on CC communication channel (through the CC' connection **524**). The controller **534** can also control voltage converter **560** to control the amount of voltage step down. Alternatively, voltage converter **560** can provide only a fixed step-down of the voltage without controlled adjustment.

[0052] With reference to the converter circuitry **514**, the controller **535** includes microprocessor **537**, a memory **539**, a CC wire interface **541** and a CC communication channel interface **543**. The controller **535** can send and receive information/data on CC wire **518** and can send and receive information/data on CC communication channel (through the CC' connection **524**). The controller **535** can also control voltage converter **529** to control the amount of voltage step down. Alternatively, voltage converter **529** can provide only a fixed step-down of the voltage without controlled adjustment.

[0053] A DC power injector **572** can provide a power supply at an elevated voltage to the high voltage wire **526** to power devices **502** and/or **504** via the step down converters **560** and **529**. The DC power injector **572** can be physically located within or external to the converter circuitry **512**. In such case, raising the voltage just for the purpose of power transmission may not be required if only port **508** and not port **510** consumes power. When both ports **508** and **510** consume power, raising the voltage for purposes of power transmission may be required if port **510** is a sufficient distance away. A second DC power injector **574** can be included within or external to the converter circuitry **514** such that the system can be powered by DC power injectors **572** and/or **574**. In exemplary embodiments, the DC injectors can include a battery, a AC to DC voltage converter that receive an AC voltage and converts the AC voltage to a DC voltage that is injected into the circuitry, and/or can be another suitable DC voltage source.

[0054] FIG. **6** shows another exemplary cable extension system **600**. In the system **600** shown in FIG. **6**, converter circuitry **612** includes controller **634** and step down converter **660** and converter circuitry **614** includes controller **635** and step-down converter **629**.

[0055] With reference to the converter circuitry **612**, the controller **634** includes microprocessor **636**, a memory **638**, a CC wire interface **640** and a CC communication channel interface **642**. The controller **634** can send and receive information/data on CC wire **616** and can send and receive information/data on CC communication channel (through

the CC' connection **624**). The controller **634** can also control voltage converter **660** to control the amount of voltage step down. Alternatively, voltage converter **660** can provide only a fixed step-down of the voltage without controlled adjustment.

[0056] With reference to the converter circuitry **614**, the controller **635** includes microprocessor **637**, a memory **639**, a CC wire interface **641** and a CC communication channel interface **643**. The controller **635** can send and receive information/data on CC wire **618** and can send and receive information/data on CC communication channel (through the CC' connection **624**). The controller **635** can also control voltage converter **629** to control the amount of voltage step down. Alternatively, voltage converter **629** can provide only a fixed step-down of the voltage without controlled adjustment.

[0057] A DC power injector **672** can provide a power supply at an elevated voltage to the high voltage wire **626** to power devices **602** and/or **604** via the step down converters **660** and **629**. The DC power injector **672** can be physically located within or external to the converter circuitry **612**. In such case, raising the voltage just for the purpose of power transmission may not be required if only port **608** and not port **610** consumes power. When both ports **608** and **610** consume power, raising the voltage for purposes of power transmission may be required if port **610** is a sufficient distance away. A second DC power injector **674** can be included within or external to the converter circuitry **614** such that the system can be powered by DC power injectors **672** and/or **674**.

[0058] In the system **600**, the converter circuitry **614** can supply DC power to another device besides the one connected to port **610** through DC jack **680**. Additionally, the converter circuitry **614** contains a DC/AC converter **676** such that the converter circuitry **614** can supply AC power to a device through AC outlet **678**. Additionally, port **610** can be a USB Type B port as well as a USB Type C port. If port **610** is a USB Type B port, then it does not have a CC pin and must advertise its power requirements to converter circuitry **614** through VBUS wire **622**. Otherwise, standard low-current five vole (5V) power will be supplied.

[0059] FIG. **7** shows another exemplary cable extension system **700**. In the system **700** shown in FIG. **7**, converter circuitry **712** includes controller **734** and step-up converter **728** and converter circuitry **714** includes controller **735** and step-down converter **729**.

[0060] With reference to the converter circuitry **712**, the controller **734** includes microprocessor **736**, a memory **738**, a CC wire interface **740** and a CC communication channel interface **742**. The controller **734** can send and receive information/data on CC wire **716** and can send and receive information/data on CC communication channel (through the CC' connection **724**). The controller **734** can also control voltage converter **728** to control the amount of voltage step up. Alternatively, voltage converter **728** can provide only a fixed step-up of the voltage without controlled adjustment.

[0061] With reference to the converter circuitry **714**, the controller **735** includes microprocessor **737**, a memory **739**, a CC wire interface **741** and a CC communication channel interface **743**. The controller **735** can send and receive information/data on CC wire **718** and can send and receive information/data on CC communication channel (through the CC' connection **724**). The controller **735** can also control voltage converter **729** to control the amount of voltage step down. Alternatively, voltage converter **729** can provide only a fixed step-down of the voltage without controlled adjustment.

[0062] In the system **700**, the converter circuitry **714** can supply DC power to another device besides the one connected to port **710** through DC jack **780**. Additionally, converter circuitry **714** contains a DC/AC converter **776** such that converter circuitry **714** can supply AC power to a device through AC outlet **778**. Additionally, port **710** can be a USB Type B port as well as a USB Type C port. If port **710** is a USB Type B port, then it does not have a CC pin and must advertise its power requirements to converter circuitry **714** through VBUS wire **722**. Otherwise, standard low-current five volt (5V) power will be supplied.

[0063] FIG. **8** shows another exemplary cable extension system **800**. Extension system **800** is similar to extension system **500** in FIG. **5**, except that the host side has a USB Type A port **808** and does not have an associated converter circuit. As shown in FIG. **8**, the device **804** can receive power via the converter circuitry **814** via external DC power injectors **872** and/or **874**, which can inject power to the power transmission or high voltage wire **826** close to the host end or the device end. The voltage converter **829** can convert the voltage received from the DC power injectors **872** and/or **874** to a voltage usable to power or charge a device **804** (e.g., generate a step-down voltage). The connected USB Type C device **804** can draw power from the VBUS **822** based on the advertised power profile from controller **835**, which includes a microprocessor **837**, a memory **839**, and a CC wire interface **841**.

[0064] FIG. **9** shows another exemplary cable extension system **900**. In extension system **900**, a voltage converter circuitry **914** is used and includes a controller **935** and a voltage converter **929**. A controller **935** has a microprocessor **937**, a memory **939**, a CC wire interface **941** connected with CC wire **916**, and a CC wire interface **943** connected with CC wire **918**. A buck-booster converter **929** converts voltage of VBUS **920** to a specific profile voltage onto VBUS **922**. The controller **935** can negotiate with the first device **902** for a power profile with highest possible voltage level (e.g. 20V) to minimize the current needed for a fixed amount of power needed by the second device **904**. The controller **935** then advertises to the second device **904** the power profile it can support accounting for the capability of the first device **902** and an expected amount of loss over the VBUS wire **920**. For example, rather than having the first device **902** transmit power at five volts (5V) and two amperes (2A), the controller **935** can request that the first device transmit power at twenty volts (20V) and five amperes (5A), and the controller **935** can advertise to the second device **904** that the power will be delivered at five volts (5V) and two amperes (2A).

[0065] FIGS. **10**A-D show multiple form factors **1010**A-D for housing an instance of converter circuitry (e.g., converter circuitry **312**, **314**, **412**, **414**, **512**, **514**, **612**, **614**, **712**, **714**, **814**, and/or **914**). For ease of identification, reference is made only to converter circuitry **312** shown in FIG. **3**, but it should be understood that the same form factors could be used with converter circuitry **314**, **412**, **414**, **512**, **514**, **612**, **614**, **712**, **714**, **814**, and/or **914** as well. In FIG. **10**A, a cable **1050** is attached to converter circuitry **312** on the same side of the housing **1010**A as the input side of step-up converter **328**. The cable **1050** has a male USB Type C plug **1052** on the opposite end to the end attached to the converter circuitry

312. Plug 1052 can connect with USB port 308 (shown in FIG. 3). The opposite side of housing containing the converter circuitry 312 includes receptacle 1054 electrically coupled to the output of the voltage converter 328 and the CC communication channel interface 342 for receiving a corresponding male connector (not shown). The male connector is part of a cable containing the CC communication channel (through the CC' connection 324) and high voltage wires 326. In FIG. 10B, cable 1050 and plug 1052 of the housing 1010A in FIG. 10A are replaced with a USB port 1056 in the housing 1010B. A USB Type C cable can connect port 308 (shown in FIG. 3) and port 1056. In FIG. 10C, receptacle 1054 shown in the housing 1010A is replaced with an attached cable containing the CC communication channel (through the CC' connection 324) and the high voltage wires 326 in the housing 1010C. In FIG. 10D, converter circuitry is mounted within housing 1010D, which can form a wall-mountable arrangement that allows the converter circuitry to be mounted inside of a wall behind a faceplate. As such, the extension cable can run through the wall.

[0066] FIG. 11 is a flowchart of a non-limiting example power delivery process 1100 in accordance embodiments of the present disclosure. The process 1100 begins at step 1102. At step 1104, a first voltage and a first electrical current is received by first converter circuitry from a first device electrically coupled to the first converter circuitry via a V-bus wire associated with a first USB connector. At step 1106, a second voltage and a second electrical current is output from the first converter circuitry on a power transmission wire. The second voltage is greater than the first voltage and the second electrical current is less than the first electrical current. At step 1108, the second voltage and the second electrical current can be received by second converter circuitry via the power transmission wire. At step 1110, a third voltage and a third electrical current can be output from the second converter circuitry to a second device via a V-bus wire associated with a second USB connector to deliver power to the second device from the first device. At step 1112, the process ends.

[0067] FIG. 12 is a flowchart of a non-limiting example power delivery process 1200 in accordance with embodiments of the present disclosure. The process begins at step 1202. At step 1204, a first voltage and a first electrical current is received by first converter circuitry that includes a first voltage converter from a first device electrically coupled to the first converter circuitry via a V-bus wire associated with a first USB connector. At step 1204, a second voltage and a second electrical current is output from the first converter circuitry to a second device via a V-bus wire associated with a second USB connector to deliver power to the second device first device. At step 1206, the process 1200 ends.

[0068] FIG. 13 is a flowchart of a non-limiting example power delivery process 1300 in accordance with embodiments of the present disclosure. In the process 1300 power can be delivered via a Universal Serial Bus cable having a USB Type-C connector at a first terminal end of the Universal Serial Bus cable and an USB Type-A connector at a second end of the Universal Serial Bus cable. The process begins at step 1302. At step 1304, a first voltage and a first electrical current is received by first converter circuitry including a first voltage converter operatively coupled to the USB Type-C connector from a DC power injector electrically coupled to the first converter circuitry. At step 1306, a second voltage and a second electrical current is output from the first converter circuitry to the USB Type-C connector via a V-bus wire associated with the USB Type-C connector to deliver power to a device. At step 1308, the process 1300 ends.

[0069] While the preferred embodiments of the devices and methods have been described in reference to the environment in which they were developed, they are merely illustrative of the principles of the inventions. The elements of the various embodiments may be incorporated into each of the other species to obtain the benefits of those elements in combination with such other species, and the various beneficial features may be employed in embodiments alone or in combination with each other. Other embodiments and configurations may be devised without departing from the spirit of the inventions and the scope of the appended claims.

1. A Universal Serial Bus (USB) power delivery system comprising:

first converter circuitry, the converter circuitry including:

a first controller having a first electrical interface configured to electrically couple to a CC wire of a first USB Type-C connector, the controller being configured to send and receive data via the first electrical interface; and

a first voltage converter having an input and an output, the first voltage converter being configured to receive a first voltage at the input and to output a second voltage at the output,

wherein the first voltage converter is configured so that (i) the input of the voltage converter is configured to be electrically coupled to a V-bus wire of the USB Type-C connector and the output of the first voltage converter is configured to be electrically coupled to a power transmission wire or (ii) the input of the first voltage converter is configured to be electrically coupled to the power transmission wire and the output of the first voltage converter is configured to be electrically coupled to the V-bus wire of the USB Type-C connector.

2. The system of claim 1, wherein the first voltage is greater than the second voltage.

3. The system of claim 1, wherein the second voltage is greater than the first voltage.

4. The system of claim 1, wherein the controller further comprises:

a second electrical interface configured to electrically couple to a CC communication channel, and the controller is configured to send and receive data via the second electrical interface.

5. The system of claim 1, further comprising:

second converter circuitry, the second converter circuitry including:

a second controller having a third electrical interface configured to be electrically coupled to a CC wire of a second USB Type-C connector and a fourth electrical interface configured to electrically coupled to the CC communication channel, the second controller being configured to can send and receive data via the third and fourth electrical interfaces; and

a second voltage converter having an input and an output, the second voltage converter being configured to output the first voltage or receive the second voltage at the input,

wherein the second voltage converter is configured so that (i) the input of the second voltage converter is configured to be electrically coupled to the V-bus wire of the USB Type-C connector and the output of the second voltage converter is configured to be electrically coupled to the power transmission wire or (ii) the input of the second voltage converter is configured to be electrically coupled to the power transmission wire and the output of the voltage converter is configured to be electrically coupled to the V-bus wire of the USB Type-C connector.

6. The system of claim **5**, wherein the first converter circuitry is electrically coupled to the second converter circuitry via the CC communication channel and the power transmission wire.

7. The system of claim **1**, wherein the power at the input of the first voltage converter is approximately equal to the power at the output of the first converter.

8. The system of claim **1**, wherein the first converter circuitry includes:

a further voltage converter, the further voltage converter; and

a switching circuit to switch between the first voltage converter and the further voltage converter.

9. The system of claim **8**, wherein switching circuit is configured to (i) electrically couple the input of the first voltage converter to the V-bus wire of the USB Type-C connector and the output of the first voltage converter to the power transmission wire or to (ii) electrically couple the input of the further voltage converter to the power transmission wire and the output of the further voltage converter to the V-bus wire of the USB Type-C connector.

10. The system of claim **1**, wherein the first converter circuitry includes a DC power injector that supplies power on the power transmission wire.

11. The system of claim **5**, wherein the second converter circuitry includes a DC/AC converter to convert a first voltage or the second voltage into an AC voltage, and the system further comprises:

an AC outlet electrically coupled to the DC/AC converter.

12. The system of claim **5**, further comprising:

a jack electrically coupled to the second converter circuitry to provide a port through which a device is capable of receiving the first voltage, the second voltage, or a third voltage derived from the first voltage or the second voltage.

13. The system of claim **12**, wherein the first converter circuitry includes a DC/DC converter to convert the first voltage or the second voltage into the third voltage, and wherein the jack is electrically coupled to an output of the DC/DC converter.

14. The system of claim **5**, wherein the second converter circuitry includes:

a further voltage converter; and

a switching circuit to switch between the second voltage converter and the further voltage converter.

15. The system of claim **14**, wherein the switching circuit is configured to (i) electrically couple the input of the second voltage converter to the V-bus wire of the USB Type-C connector and the output of the second voltage converter to the power transmission wire or to (ii) electrically couple the input of the further voltage converter to the power transmission wire and the output of the further voltage converter to the V-bus wire of the USB Type-C connector.

16. The system of claim **5**, wherein the second converter circuitry includes a DC power injector that supplies power on the power transmission wire.

17. The system of claim **5**, wherein the first controller communicates with the second controller via the CC communication channel.

18. The system of claim **17**, wherein first controller communicates with the second controller to exchange information associated with managing power usage via the first and second converter circuitry.

19. The system of claim **18**, wherein the information is associated with power capabilities of a first device operatively coupled to the first converter circuitry, power needs of a second device operatively coupled to the second converter circuitry, and an expected loss power over the power transmission wire.

20. A method of delivering power via a Universal Serial Bus (USB) cable, the method comprising:

receiving, by first converter circuitry, a first voltage and a first electrical current from a first device electrically coupled to the first converter circuitry via a V-bus wire associated with a first USB connector;

outputting, from the first converter circuitry, a second voltage and a second electrical current on a power transmission wire, the second voltage being greater than the first voltage and the second electrical current being less than the first electrical current;

receiving, by second converter circuitry, the second voltage and the second electrical current via the power transmission wire; and

outputting, from the second converter circuitry, a third voltage and a third electrical current to a second device via a V-bus wire associated with a second USB connector.

21. The method of claim **20**, further comprising:

receiving, by the second converter circuitry, the first voltage and the first electrical current from the second device electrically coupled to the first converter circuitry via the V-bus wire associated with the second USB connector;

outputting, from the second converter circuitry, the second voltage and the second electrical current on the power transmission wire;

receiving, by the first converter circuitry, the second voltage and the second electrical current via the power transmission wire; and

outputting, from the first converter circuitry, the third voltage and the third electrical current to the first device via the V-bus wire associated with the first USB connector.

22. A method of delivering power via a Universal Serial Bus (USB) cable, the method comprising:

receiving, by first converter circuitry including a first voltage converter, a first voltage and a first electrical current from a first device electrically coupled to the first converter circuitry via a V-bus wire associated with a first USB connector; and

outputting, from the first converter circuitry, a second voltage and a second electrical current to a second device via a V-bus wire associated with a second USB connector.

23. A method of delivering power via a Universal Serial Bus (USB) cable having a USB Type-C connector at a first terminal end of the Universal Serial Bus cable and an USB

Type-A connector at a second end of the Universal Serial Bus cable, the method comprising:

receiving, by first converter circuitry including a first voltage converter operatively coupled to the USB Type-C connector, a first voltage and a first electrical current from a DC power injector electrically coupled to the first converter circuitry; and

outputting, from the first converter circuitry to the USB Type-C connector, a second voltage and a second electrical current via a V-bus wire associated with the USB Type-C connector.

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